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THESIS

DETERMINATION OF CRITICAL FACTORS IN UNMANNED CASUALTY EVACUATION IN THE DISTRIBUTED ENVIRONMENT

by

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June 2009

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13. ABSTRACT (maximum 200 words)

The current battlefield is changing rapidly. Combat operations against irregular forces are set in a dispersed, non-linear battlefield. Vast distances between small units such as the infantry squad, and the distances from these small elements to their supporting organizations, pose unique challenges.

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Unmanned aerial systems offer an alternative means of air casualty evacuation. This alternative may provide time-critical response while reducing threat to aircraft crews.

The thesis determined the probability distribution of mission completion times and identified the most influential factors on mission success.

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DETERMINATION OF CRITICAL FACTORS IN UNMANNED CASUALTY EVACUATION IN THE DISTRIBUTED ENVIRONMENT

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THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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List of ACRONYMS AND ABBREVIATIONS

ABM	Agent based model
CASEVAC	Casualty Evacuation
CONUS	Continental United States
DASC	Direct Air Support Center
DTA	Defense Technology Agency
EAF	Expeditionary Airfield
ECO LOE	Enhanced Company Operations Limited Objective Experiment
EO/IR	Electro-optical/infrared
FRSS	Forward Resuscitative Surgical Suite
JT	Javelin Thrust
JTEAM	Joint Test and Evaluation Agent Model
MAGTF	Marine Air Ground Task Force
MCWL	Marine Corps Warfighting Laboratory
MEB	Marine Expeditionary Brigade
MEDEVAC	Medical Evacuation
MLG	Marine Logistics Group
MOE	Measures of Effectiveness
MTF	Medical Treatment Facility
MWTC	Mountain Warfare Training Center
NOLH	Nearly Orthogonal Latin Hypercube
NPS	Naval Postgraduate School
NST	Netcentric Systems Test office

OPFOR	Opposition Force
POI	Point of Injury
SEED	Simulation Experiments and Efficient Design
SP	Safety Pilot
TACC	Tactical Air Control Center
TCDL	Tactical Common Data Link
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial System
ULB	Unmanned Little Bird
VRS	Vortex Ring State

EXECUTIVE SUMMARY

The dispersed nonlinear battlefield presents a dynamic operating environment. Increased dispersion between units as small as the infantry squad and their supporting organizations pose unique challenges, and casualty evacuation (CASEVAC) is one of these challenges. The first 60 minutes after a traumatic injury is referred to as the "golden hour." The chances of survival for critically injured trauma patients depend on immediate surgical care. Delivering an injured Marine to adequate surgical care within the golden hour is the goal of CASEVAC.

Aerial CASEVAC, executed with manned assets, places additional lives at risk. Unmanned aerial systems (UASs), however, offer an alternative means of air CASEVAC. This alternative may provide a time-critical response, while reducing the threat to aircraft crews.

This thesis provides the Marine Corps Warfighting Laboratory (MCWL) with analytical support for initial and further development of possible tactics, techniques, and procedures for unmanned CASEVAC. This thesis is guided by two questions:

- What is the probability distribution of mission completion time?
- What are the most influential factors that affect mission completion time?

This thesis uses agent-based simulation, state-of-the-art design of experiments, and statistical analysis to investigate these questions.

The goal of the simulation is to quantify the effects of multiple factors in the successful completion of an unmanned CASEVAC mission. The measure of effectiveness is the number of CASEVACs completed within the golden hour. The factors include: UAS speed, UAS quantity, UAS capacity, and the number and location of casualties.

The scenario expands upon the UAS CASEVAC portion of the Enhanced Company Operations Limited Objective Experiment 3.3 (ECO LOE 3.3). ECO LOE 3.3 is a live force experiment conducted by MCWL in June 2009. In the simulation, there are

three platoon locations, separated by over 50 miles. Casualties occur between 5 and 45 miles away from surgical care. There is an enemy presence that is located either along the route of flight, near the point of injury (POI), or a combination of both.

The Joint Test and Evaluation Model (JTEAM) is the program of choice for this thesis. This farmable model provides the flexibility to capture the key factors that plague this environment and has the additional capability to simulate command and control systems. As a fast-running model, JTEAM explores the design space through thousands of simulation runs. Nearly Orthogonal Latin Hypercubes (NOLHs) and data farming enable analysis of a large set of possibilities.

The conclusions are based on simulation runs with varying levels of assets, capacities, and UAS capabilities. The detailed quantitative analysis of the simulation results reveals the number of UASs, the number of litters and airspeed required to respond to the simulated number, and the location of casualties within the golden hour. Three UASs, with two litters per UAS, are recommended. With this allocation of assets, the capabilities of the current concept demonstrator, Boeing's Unmanned Little Bird, appear sufficient to achieve an acceptable mission completion time.

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I. UNMANNED AIR CASUALTY EVACUATION (CASEVAC) IN THE DISTRIBUTED ENVIRONMENT

A. CASEVAC: A TIME-CRITICAL MISSION

Quickly delivering an injured Marine to adequate surgical care is the goal of casualty evacuation (CASEVAC). The first 60 minutes after a traumatic injury is referred to as the “golden hour.” The chances of survival for critically-injured trauma patients depend on immediate surgical care. Aerial CASEVAC, executed with manned assets, places additional lives at risk. Unmanned aerial systems (UASs) offer an alternative means of air CASEVAC. This alternative may provide time-critical response, while reducing the threat to aircraft crews (Hill, Konoske, Galarneau, & Pang, 2003).

1. The Methods of CASEVAC have Evolved

In 1792, French surgeon Dominique Jean Larrey began removing injured soldiers from the battlefield on two-wheeled, horse-drawn carriages. In World War II, short takeoff and landing planes, such as the Piper J–3, were used. Helicopters, the current vehicle of choice for aerial CASEVAC, were used for the first time in the Vietnam War.

The Marine Corps does not have a dedicated aerial CASEVAC platform; however, the Marine Air Ground Task Force (MAGTF) commander can assign CASEVAC missions to lifts of opportunity. The MV–22 Osprey is the most capable asset at the MAGTF commander’s disposal because of its speed and high flight ceiling. These attributes allow the MV–22 to fly above small-arms fire and many man-portable, surface-to-air missile systems (Hill et al., 2003).

Although the MV–22 is very capable, it has limitations. One such limitation is the MV–22’s susceptibility to vortex ring state (VRS), which is a condition experienced when the MV–22 descends quickly with low forward airspeed. While all rotary wing aircraft are susceptible to VRS, traditional helicopters can descend at a high rate of speed and flare just above the ground to arrest this descent. VRS prevents the MV-22 from making fast insertions, thus limiting its utility in unsecured landing zones (Berler, 2005).

2. Care is Provided at Different Levels

After being evacuated to life-saving surgical care, patients are then moved to advanced treatment. Five levels, or echelons, of care are used.

- Level I is the first echelon of care and is provided by first responders at the unit level.
- Casualties are evacuated from the point of injury (POI) to level II care, where life-saving surgical care is provided.
- After receiving surgical care, casualties are then moved to level III, a theater hospital, where more comprehensive care is provided.
- Level IV is characterized by longer hospitalization in theater and possibly in the continental United States (CONUS).
- Level V care is convalescent, restorative, and rehabilitative care, and is normally provided in CONUS (Schoo, 2006).

B. CASEVAC EXECUTION REQUIRES AN ADAPTIVE APPROACH

1. Ineffective CASEVAC can Cost Lives

The increased dispersion between units as small as the infantry squad and their supporting organizations pose unique challenges, and CASEVAC is one of these challenges. The patient is stabilized before transport because, unlike medical evacuation (MEDEVAC), emergency care may not be provided en route. Treatment time lost en route, and greater distances from the POI to life-saving surgical care, creates a need for faster reaction and reduced travel times. The nonlinear aspects of this battlefield pose a threat to the crews and platforms conducting CASEVAC as they operate over unsecured areas (Conway, 2008).

Medical personnel can be placed on aerial CASEVAC platforms to provide treatment from the POI to level II care. Although this addition allows for treatment en route, loading these assets to a lift of opportunity could consume valuable time. This approach also does not mitigate the risk to manned aircrews (Hill et al., 2003).

2. The Use of UASs Offer an Alternative Method for Aerial CASEVAC

The use of UASs in CASEVAC reduces the exposure of aircrews to enemy fire. Although not equipped to provide care en route, time is not lost configuring the aircraft for medical personnel and supplies. A disadvantage of using UASs is their inability to autonomously react to an enemy threat without safety pilot (SP) control.

C. RESEARCH QUESTIONS

This thesis simulates the UAS CASEVAC portion of the Enhanced Company Operations Limited Objective Experiment 3.3 (ECO LOE 3.3) specifically by conducting a comparative, quantitative analysis of the use of UASs for the CASEVAC mission. The following questions are addressed:

- What is the probability distribution of mission completion time?
- What are the most influential factors that affect mission completion time?

D. METHODOLOGY

1. Agent-Based Simulation Used to Model a Dynamic Environment

A low-resolution, agent-based model (ABM) simulates approved scenarios for analysis. The Joint Test and Evaluation Agent Model (JTEAM) is used to model UAS interaction in the distributed environment.

JTEAM is a prototype agent-based simulation developed in support of the Netcentric Systems Test (NST) office. This thesis is the first ever to use JTEAM. Pythagoras was originally developed by Northrop Grumman in support of Project Albert (a research project designed to evaluate nontraditional simulation techniques). ABMs are useful for addressing those areas of combat omitted from many combat models, to include nonlinearity, intangibles, and a coevolving landscape (Bitinas, Henscheid, & Truong, 2003). JTEAM and Pythagoras allow the simulation to capture critical factors of interest without modeling all the physical details, and allow the user to alter input parameters during the simulation execution.

2. Advanced Design of Experiments Explores Simulation Results

The model runs thousands of simulated CASEVACs across a range of conditions and assumptions. In addition, state-of-the art design of experiments and data analysis techniques are used to analyze the critical factors associated with the ability of an unmanned system to provide aerial CASEVAC. The model is analyzed as it is replicated. Data farming methods are used to quantify how varying the input factors in the model affect the measures of effectiveness (MOEs) over the range of scenarios. The resulting analysis provides insights through the exploration of different outcomes.

E. PURPOSE AND ORGANIZATION

1. Develop Tactics, Techniques, and Procedures (TTPs) for UASs in CASEVAC

The purpose of this thesis is to conduct a simulation study, using an ABM, which provides insights on possible future TTPs for the use of UASs in CASEVAC. The Marine Corps Warfighting Laboratory (MCWL) will conduct ECO LOE 3.3 in June 2009, in the Mountain Warfare Training Center. One goal is to assess the performance of a UAS as an alternative means of air CASEVAC.

The proposed UAS, Boeing's Unmanned Little Bird (ULB), will be used in ECO LOE 3.3. The ULB is the concept demonstrator; however, this thesis evaluates a range of performance characteristics of unmanned systems for aerial CASEVAC (Marine Corps Warfighting Laboratory, 2008).

2. Thesis Organization

Chapter II provides a description of MCWL's exercise and the ULB. Also included are an overview of JTEAM, Pythagoras, and a detailed description of the simulation model. Chapter III provides a discussion of the design of experiments and includes a description of the key factors. Chapter IV provides a description of the analytical methods used to interpret the results of the simulations and an explanation of those results. Chapter V completes this thesis with a discussion of insights gained from the analysis and recommendations for follow-on research.

II. UNMANNED AERIAL SYSTEM CASEVAC MODEL

The current battlefield is changing rapidly. This battlefield consists of combat operations against irregular forces set in a dispersed, nonlinear environment. The JTEAM model, along with the ECO LOE 3.3, provides insights into the potential benefits from using unmanned aerial systems for CASEVAC in this environment.

A. THE DISTRIBUTED ENVIRONMENT PLACES ADDITIONAL DEMANDS ON THE COMPANY

1. ECO are Motivated by Low Intensity Conflict

The concept for ECO provides a basis for on-going infantry company-focused combat development that will allow the MAGTF to succeed against hybrid threats in a dispersed, nonlinear battlefield. As our deployed forces have verified, modern conflicts will place increasing demands on maneuver elements below the battalion level.

While current doctrine still regards the battalion as the lowest echelon of maneuver capable of sustained operations, this stance is shifting. On today's battlefield, the infantry company must be capable of collecting, analyzing, and distributing information; requesting, coordinating, and controlling all forms of fire support; and planning and executing sustainment operations. The result of ECO could be referred to as a company-sized MAGTF. Informal analysis of ECO in the area of logistics concludes that unmanned aerial and ground systems are a potential solution, in distributed high threat situations, for the delivery of critical supplies and for moving injured Marines (Conway, 2008).

2. Forward Resuscitative Surgical Suite (FRSS) Provides Care

The FRSS is set up and operated by personnel from the Surgical Company from the Marine Logistics Group (MLG). The FRSS would normally be established in an austere forward location to enable responsive life- saving surgery. In the early stages of an amphibious operation, the FRSS might be the only surgical care ashore until a more robust medical treatment facility is established in the MAGTF's Support Area. If an FRSS is not available during the early stages of an amphibious operation, critically wounded Marines would be moved to a sea-based medical facility.

B. REAL-WORLD UNMANNED CAPABILITIES TESTED

The ECO LOE 3.3 is scheduled to occur after thesis completion. The MCWL will employ Boeing's ULB as a resupply and CASEVAC concept demonstrator during the experiment. ECO LOE 3.3 will take place as part of a large-scale 4th MLG exercise, Javelin Thrust 09 (JT-09), in the Mountain Warfare Training Center (MWTC) in June 2009.

1. Aerial CASEVAC Examined in ECO LOE 3.3

The experiment will test the ability of the UAS to accomplish the CASEVAC mission under a variety of scenarios. The UAS will be used to conduct two CASEVAC missions. JT-09 was planned to represent a Marine Expeditionary Brigade (MEB)-sized MAGTF. The 23rd Marines will provide the ground component of this exercise. I Company, 3d Battalion, 23rd Marines (I Co., 3/23) will act as the exercise opposition force (OPFOR). I Co., 3/23, along with selected combat service support elements from the 4th MLG, will also be tasked to be the experimental forces in support of the MCWL LOE.

While operating as the exercise OPFOR, I Co. 3/23 will conduct two simulated CASEVAC missions using Boeing's ULB as the concept demonstrator. Injecting a scripted critical injury of one of the OPFOR Marines will simulate each CASEVAC mission. The role of the injured Marine will be simulated with a medical dummy loaded onto the aircraft. To simplify experiment control, ULB flights will be limited to takeoffs and landings at the Expeditionary Airfield (EAF) located at MWTC. This will result in short mission legs that detract from the challenges presented in the dispersed environment.

2. The ULB Provides a Unique Opportunity for Live Force Experimentation

Boeing's ULB offers a versatile and reliable platform for conducting live experiments that examine the potential for a logistics UAS. The ULB originated from a 1960s series of light attack and observation helicopters. Converted from the commercial MD530 F helicopter, the ULB could be crewed by two personnel, with seating for two additional personnel in the cabin. U.S. Army Special Forces have flown this aircraft with four soldiers on the skids for rapid deployment.

Figure 1. Boeing's Unmanned Little Bird (From: Boeing, 2006)

With a maximum speed of 134 mph, a range of 379 miles, and flight ceiling of 7,300 ft, the ULB is well suited for use as an experimental aircraft in the context of ECO-based live force experiments. Its small size (23-ft length, 26.35-ft width, and 8.14-ft height) allows for entry into landing zones that would otherwise be impractical for larger aircraft. The ability to take off with a maximum weight greater than 3,500 lbs provides the flexibility to deliver supplies and transport casualties (Boeing, 2009).

The Little Bird executed its first unmanned flight in June 2006. After takeoff, the ULB flew a 20-minute programmed route around the U.S. Army's Yuma Proving Ground in Yuma, Arizona. It landed within six inches of the planned recovery location. The test payload was 740 lbs. The ULB lifted off weighing 3,000 lbs and could have added an additional 550 lbs (Boeing, 2006). It has an onboard sensor suite comprised of an electro-optical/infrared (EO/IR) sensor and a Tactical Common Data Link (TCDL) communication system.

3. The ULB System is Designed for a Fluid Environment

The ULB can be controlled in two ways. The flight path can be programmed before launch or an SP at the ground control station (GCS) can control the aircraft. From the GCS, the SP can upload a new set of waypoints to the ULB or can assume manual control. If data link communication is lost with the ULB, it reverts back to its programmed flight path. Onboard navigation is provided by a commercial global positioning system (GPS). The ULB lands via digital terrain elevation data (DTED) and a radar altimeter (RADALT) positioned between the skids (Potashnik, 2008).

The GCS is Boeing's Operational Mission Management System (OMMS). OMMS is comprised of two main subsystems: the SP's station and the TCDL communication system. The SP has two laptops: one has a dual display, which operates software, and the second displays TCDL information.

The TCDL system is used to relay location, system status, and real-time video to the GCS. En route adjustments are made via the TCDL. The ULB must maintain line of sight communications (LOS) with the GCS to utilize the TCDL. A radio relay system would extend the range of control indefinitely. Components of the TCDL are shown in Figure 2: three line replaceable units (LRUs), a 9-ft, dual-axis directional antenna, Radio Frequency Equipment (RFE), and data modem (Cerchie, Docker, Graham, Guthrie, & Hardesty, 2008).

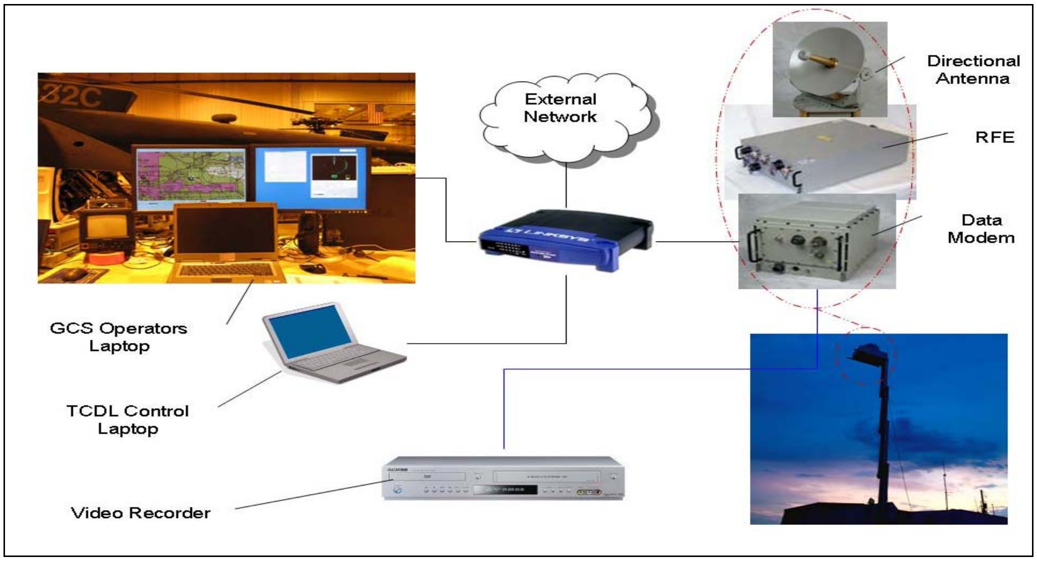

Figure 2. Ground Control Station Components (From: Cerchie et al., 2008)

4. Unmanned Aerial CASEVAC and Logistics Capabilities Evaluated

In April 2008, MCWL performed a limited technical assessment (LTA) of the ULB. The LTA tested the autonomous behaviors of the aircraft to include en route mission updates. Test flights included mission profiles representing both resupply and CASEVAC. The LTA results validated the ability of the ULB to serve as a concept demonstrator. During the two CASEVAC flights, the ULB took off, flew to the casualty, and landed autonomously using the RADALT. Figure 3 shows the ULB configured with a rescue basket and a canister for resupply.

Figure 3. ULB configured with resupply canister and rescue basket (From: Cerchie et al., 2008)

The time required for the ULB to descend from level flight, retrieve the casualty, and resume level flight was 5.3 minutes. This leaves 54.7 minutes remaining in the "golden hour" to complete the CASEVAC mission. To achieve mission success, the first responder must render aid and inform the company leadership of an evacuation need; the company must request a CASEVAC from the Direct Air Support Center (DASC); and the UAS must then fly to the POI and back to the FRSS within the remaining 54.7 minutes.

In the resupply role, the ULB delivered a 600-lb load, using the external cargo hook, approximately 37 miles in 25 knot winds, with limited inputs by the SP. Figure 4 shows the ULB configured with sling-loaded cargo underneath the aircraft.

Figure 4. ULB with external hook sling load (From: Cerchie et al., 2008)

Smaller loads can be placed in converted napalm canisters or in the rescue basket (Potashnik, 2008). Figure 5 shows a ULB with two canisters and a sling load.

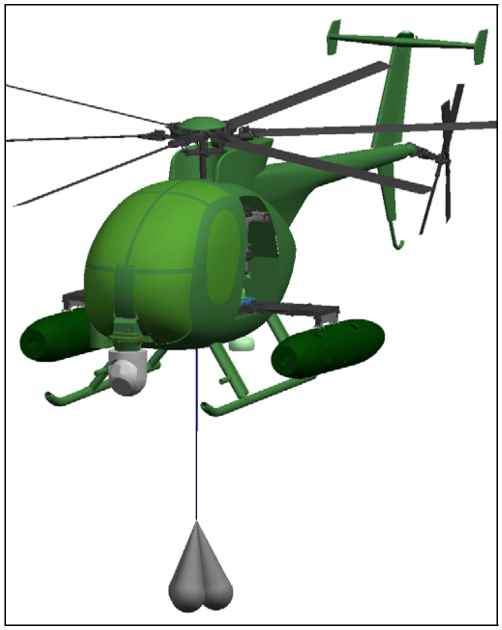

Figure 5. ULB configuration with sling load and two canisters (From: Cerchie et al., 2008)

5. What Could a Future Logistics UAS Structure Look Like?

To provide a robust alternative to unmanned ground and air logistics support, each Marine Expeditionary Force (MEF) Air Combat Element (ACE) might include one Marine Unmanned Logistics Helicopter Squadron (HULM) as part of each Marine Aviation Group. The HULM would consist of 10 to 12 aircraft. During combat operations, this squadron could form detachments consisting of two or more aircraft, two ground control stations, and 30 operators and crew support (MCWL, 2008).

C. JTEAM MODELS COMPLEX ENVIRONMENTS

1. What is JTEAM?

JTEAM is a farmable ABM; discrete-event and three-dimensional. Time is measured in seconds and space in meters. Both values are represented by floating point numbers, which allow the operating area to be scaled to any size. Although the default units of time and distance are seconds and meters, respectively, these can be tailored as long as the units remain consistent. Terrain is not a feature of the JTEAM model (JTEAM Version 1.0 User Manual, 2008).

JTEAM is written in Java and uses the MASON ABM for its underlying infrastructure. Additional functionality is provided through other supporting programs. The George Mason University Evolutionary Computation Laboratory developed the MASON ABM as the foundation for larger simulations.

2. Why was JTEAM Chosen?

The dispersed nonlinear battlefield presents a dynamic operating environment. The JTEAM model provides the flexibility to capture the key factors that plague this environment. Other ABMs can simulate the interactions of terrain, weather, friendly forces, and enemy combatants, and their effects on mission accomplishment.

JTEAM has the ability to model these factors and has the additional capability to simulate command and control systems. Like traditional models, JTEAM can simulate the reliability of communications, but unlike those models, JTEAM can use those communications to trigger events.

Like traditional models, JTEAM is farmable; input parameters associated with agents can be varied to enhance computational experiments. JTEAM offers flexibility; users can develop software components to extend the functionality of the basic framework. JTEAM also allows users to construct agents that are specific to the domain. As a fast-running model, JTEAM explores the design space through thousands of simulation runs.

3. JTEAM Agents

Decider, Effector, and Perceiver components form the basic structure and functionality for each agent. Effectors, Perceivers, and Deciders have associated farmable parameters. Currently, there is only one Perceiver implemented, a SimpleThreatPerceiver. This uses an observation and a low level Percept to determine whether an observed Agent is a threat. Action, effector, communications, damage, and perception handling mechanisms characterize the structure of the component. The agent structure also includes target and observable classes.

a. Effectors Provide a Means to Observe the Environment

Through sensing, movement or shooting an agent can influence the surrounding environment. Agents can only take actions provided by the assigned set of Effectors. In addition to actions, Effectors can also provide Percepts to an agent.

b. Perceivers Determine what an Agent "Knows"

Perceivers create new Percepts. Percepts are data structures only; they are not farmable. These attributes are used to model operator overload or memory. They are used by the Deciders to implement action. Knowledge is passed from one agent to another through messages with imbedded Percepts.

c. Deciders Implement Courses of Action

Deciders use Percepts to implement courses of action and direct Effectors to execute those actions. Although an agent can possess multiple Effectors and Perceivers, agents are currently limited to one Decider. Deciders can, however, differ from one agent type to another (JTEAM Version 1.0 User Manual, 2008). A more in-depth coverage of Effectors, Percepts, and Deciders can be found in the *JTEAM Version 1.0 User Manual*.

4. Functionality Programmed in JTEAM

A casualty event is generated based on the uniform distribution; the default is the interval (0, simulationStopTime). The user can specify a different interval to model different casualty generation scenarios and can turn casualties on and off, where a 0 indicates that a casualty will not be in that particular replication, and a 1 says it will occur.

The CASEVAC message originates from the first responder (corpsman). This request also includes the location of the casualty, which gets passed to the DASC and, subsequently, the UAS. The DASC forwards a CASEVAC mission request message, which tasks the UAS.

A mission tasker in the DASC allows the UAS to be assignment based on priority. A mission list is held at the DASC. A UAS is available for retasking after a mission is completed.

The Casualty Evacuation Mission Tasker is a Java class that serves as the mission tasker in the DASC. It has a resource database that identifies which agents can serve as carriers, each capacity, assignment distance (how far away they can be to assign the agent), and pickup radius. It also has decision time, decision time offset, and update parameters that account for decision-making delays.

Agent Carriers are comprised of capacity and pickup radius. The UAS will only retrieve casualties within the pickup radius when it arrives at the casualty location.

Evaluate mission is a Java method that causes the Casualty Evacuation Mission Tasker to cycle through open requests and assign priority. Other requests can be added to the assigned mission if those other requests are within pickup radius of the UAS. This functionality allows the UAS to retrieve casualties within the pickup radius when CASEVAC requests are received while the UAS is en route to a casualty location. No en route retasking is built into this model.

The route planner determines how an agent moves from one location to another using altitude and an approach distance, which is the distance from the start/end point where the UAS starts ascent/descent.

D. THE UAS CASEVAC MODEL HAS IMMEDIATE APPLICATION

The CASEVAC model developed in JTEAM expands on the ULB’s experimentation in ECO LOE 3.3 and provides MCWL with insights into its performance in real-world scenarios. The model will also determine the critical factors that influence CASEVAC mission success.

1. Basic Assumptions for CASEVAC Model

This simulation has a specific focus: To provide TTPs in the implementation of UAS CASEVAC. The assumptions include:

- All casualties are properly stabilized and triaged before transport.
- Patient status does not degrade during the evacuation flight.
- Surgical care is collocated with the ULB launch and recovery site.
- All radio communications are reliable.

2. Agent Descriptions

Five agent types are used in this simulation: the casualty, the UAS, the DASC, the surgical care facility, and the threat.

- The UAS agents used in the model were constructed with location, speed, survivability, capacity, and route characteristics.
    - CASEVAC—When casualty notification is received, the UAS flies to the location of the casualty, retrieves the casualty, and then moves to the drop-off location.
- In the models used for this thesis, the surgical treatment facility agent represents the location and functionality of an FRSS.
- The DASC receives and processes all CASEVAC requests.
- The enemy combatants are given a location, sensor range, probability of detection, and probability of kill characteristics.
- Casualty agents are characterized by instances and location.

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III. DATA FARMING IS CRITICAL FOR EXPERIMENTAL DESIGN

This thesis used data farming to provide insights that enhance the potential effectiveness of unmanned aerial CASEVAC. Data farming involves running a simulation model many times, while simultaneously varying input parameters. The resulting output is analyzed to gain an understanding over the range of possible outcomes. State-of-the-art experimental design is used to explore the problem space through the use of Nearly Orthogonal Latin Hypercubes (NOLHs). Experimental design includes the selection of factors and MOEs.

A. THE GOLDEN HOUR MEASURES EFFECTIVENESS

An aerial CASEVAC mission is considered successful when the casualties are safely delivered to life-saving surgical care within an hour. The proportion of missions that complete within the golden hour is the MOE used in this thesis.

B. EXPERIMENTAL FACTORS DRIVE THE SCENARIO

The conditions of the distributed environment influence the choice of experimental factors. These factors are grouped into four categories: situational, aircraft characteristics, mission process times, and enemy capabilities. Aircraft characteristics and mission process times are controllable factors. Situational and enemy capabilities are uncontrollable by the decision maker. Table 1 summarizes the input parameters and ranges used in the experiment.

Factor	Value Range	Explanation
Casualties	1…18	The number of casualties sustained
Casualty Location(m)	8045…72405	The distance of the casualty from surgical care
UASs	1...4	The number of UASs available
Speed (m/s)	46.3...115.7	Airspeed (meters per second)
Litters	1...6	The number of rescue litters that are carried by each UAS
Altitude (m)	304.8…1524	The cruise altitude of the UAS
Load (s)	300...420	Time for UAS to descend, land, and climb to level flight
Enemy Sensor Range (m)	0…4828	Sensor range of the enemy
Enemy Threat Level	0...3	0=No threat; 1= Route threat; 2= Area threat; 3= Both route and area
Probability of Kill	0.005…0.03	The probability that the enemy shoots down a UAS

Table 1. Variable factors in the experimental design. Blue: situational factors, Green: aircraft characteristic factors, Yellow: mission process time factors, and Gray: enemy capability factors. [Best viewed in color.]

1. Situational Factors Set the Stage

These factors model the agents that require evacuation.

- ***Casualty Location:*** Three platoon locations vary between 8,045m (5 miles) and 72,405m (45 miles) from the forward operating base (FOB). Any casualty inside of 5 miles is ground evacuated.
- ***Number of Casualties:*** This is the number of casualties sustained by the company. These casualties require evacuation.

2. Aircraft Characteristics Determine Performance

These factors simulate current and future capabilities of unmanned systems.

- ***Number of Assets:*** The number of UASs is varied to evaluate the impact of more assets.
- ***Maximum Speed:*** This is the maximum airspeed of the UAS.
- ***Litters:*** The number of rescue litters on each UAS.
- ***Altitude:*** This is the flight altitude of the UAS.

3. Mission Process Times Model Delays

These factors model the time delays associated with information flow and decision-making. The only key factor is load time. The others are modeled as time delays within the simulation, which are listed below.

a. Load

The time required for the UAS to descend from level flight, land, and resume level flight. In the JTEAM model, the UAS descends and climbs at its cruise airspeed. This delay is a technique to artificially model the difference in descent and climb rates of each UAS. The load times are based on the results of the limited technical assessment performed on the ULB in 2008.

- ***Corpsman:*** The time required for the first responder to provide care, determine the needs for evacuation, and pass that information up the chain of command. This ranged from three to six minutes.
- ***Company:*** The time required for company leadership to receive, process, and request a CASEVAC mission. This delay ranged from 10–15 minutes.
- ***DASC:*** The time required for the DASC to process and assign an asset to the CASEVAC mission, which ranged from 6–12 minutes.
- ***Unload*:** The time required to unload the casualty upon reaching surgical care. The unload time was set at half the load time.

4. Enemy Composition is Uncontrollable

These factors account for the uncertainty associated with predicting enemy capabilities and ensure that conclusions are based upon a broad exploration of the enemy threat. Enemy presence is a categorical variable with four levels. These levels indicate where the enemy is located: 0 indicates there is no threat present, 1 indicates there an enemy presence along the route of flight; 2 indicates an enemy presence near the POI; and 3 indicates a threat along the route of flight and in close proximity to the POI.

- ***Sensor Range*** refers to the enemy's ability to acquire and track a helicopter-sized target during the day with the naked eye.
- ***Probability of Kill*** is the probability that the enemy kills a UAS.

5. Scenarios Model Threats

The scenario resembles the environment of ECO LOE 3.3. Three platoon locations are separated by over 50 miles. The FOB is centrally located with UAS support and surgical care. In the base case, there is no threat. This represents a casualty-causing event with a fleeing threat. Three different threat cases are used.

- ***High Threat:*** The high threat case models a casualty-causing event in which the threat is located in close proximity to the POI and along the UAS's flight route.
- ***Area Threat:*** The threat is near the POI.
- ***Route Threat:*** The threat, in this case, is located along the flight route.

Although enemy parameters are varied throughout the development of the model, sensor range and P_k are fixed for the final analysis. The sensor range is set at 4000m for route agents and 500 meters for area agents. The P_k is set at 0.01.

C. NOLH FOCUSES EFFORT

NOLHs are a space-filling experimental design technique developed in 2002 by COL Thomas Cioppa, United States Army, at the Naval Postgraduate School (NPS). This technique allows for the exploration of a large number of input parameters in an efficient number of runs, while maintaining nearly orthogonal design columns (Cioppa & Lucas, 2007, p.45).

Using a full-factorial approach, a design of ten factors at two levels requires over 30,000 runs (1,024 design points x 30 reps = 30,720 total runs). An NOLH allows for the exploration of the same design space with nearly 1,000 runs (33 design points x 30 reps = 990 total runs) and the factors are more extensively varied. A crossed design is then applied, UAS parameters are crossed with threat categories, creating a 4x33 table and 3960 (4x990) runs. Figure 6 shows the NOLH design spreadsheet, Figure 7 shows the Scatterplot matrix of the experimental factors, and Figure 8 shows the correlation matrix.

low level	1	1	8045	46.3	1	304.8	300	0	0.005	0
high level	18	4	72405	115.7	6	1524	420	4828	0.03	3
decimals	0	0	2	2	0	2	2	2	2	0
factor name	numCas	numUAS	CasLoc	maxSpeed	Litters	Altitude	loadTime	SensRng	P_k	Enemy
	18	1	36202.5	59.31	5	1066.8	382.5	2263.13	0.03	2
	16	4	16090	72.33	3	533.4	390	1508.75	0.03	1
	16	2	66371.25	57.14	1	1028.7	386.25	150.88	0.01	3
	11	4	72405	74.49	6	495.3	397.5	301.75	0.02	0
	17	1	38213.75	61.48	4	1181.1	348.75	2715.75	0.01	0
	17	4	28157.5	65.82	3	571.5	318.75	4224.5	0.01	2
	13	2	70393.75	63.65	1	1104.9	345	4375.38	0.03	0
	10	3	68382.5	70.16	6	609.6	326.25	4828	0.02	3
	12	2	22123.75	83.17	5	685.8	300	905.25	0.02	2
	14	3	26146.25	94.01	2	952.5	311.25	1810.5	0.03	1
	13	2	56315	113.53	3	381	315	754.38	0.01	2
	14	3	50281.25	111.36	5	1485.9	356.25	1961.38	0.01	0
	11	1	20112.5	85.34	4	457.2	416.25	3771.88	0.01	1
	15	3	32180	107.03	2	990.6	412.5	3470.13	0.01	2
	12	2	62348.75	109.19	3	304.8	378.75	3621	0.02	1
	15	3	46258.75	115.7	5	1409.7	367.5	3168.38	0.03	2
	10	3	40225	81	4	914.4	360	2414	0.02	2
	1	4	44247.5	102.69	2	762	337.5	2564.88	0.01	1
	3	1	64360	89.68	4	1295.4	330	3319.25	0.01	2
	3	3	14078.75	104.86	6	800.1	333.75	4677.13	0.02	0
	8	1	8045	87.51	1	1333.5	322.5	4526.25	0.02	3
	2	4	42236.25	100.52	3	647.7	371.25	2112.25	0.03	3
	2	1	52292.5	96.18	4	1257.3	401.25	603.5	0.03	1
	6	3	10056.25	98.35	6	723.9	375	452.63	0.01	3
	9	2	12067.5	91.84	1	1219.2	393.75	0	0.02	0
	7	3	58326.25	78.83	2	1143	420	3922.75	0.02	1
	5	2	54303.75	67.99	5	876.3	408.75	3017.5	0.01	2
	6	3	24135	48.47	4	1447.8	405	4073.63	0.02	1
	5	2	30168.75	50.64	2	342.9	363.75	2866.63	0.02	3
	8	4	60337.5	76.66	3	1371.6	303.75	1056.13	0.02	2
	4	2	48270	54.98	5	838.2	307.5	1357.88	0.02	1
	7	3	18101.25	52.81	4	1524	341.25	1207	0.01	2
	4	2	34191.25	46.3	2	419.1	352.5	1659.63	0.01	1

Figure 6. NOLH Design Spreadsheet

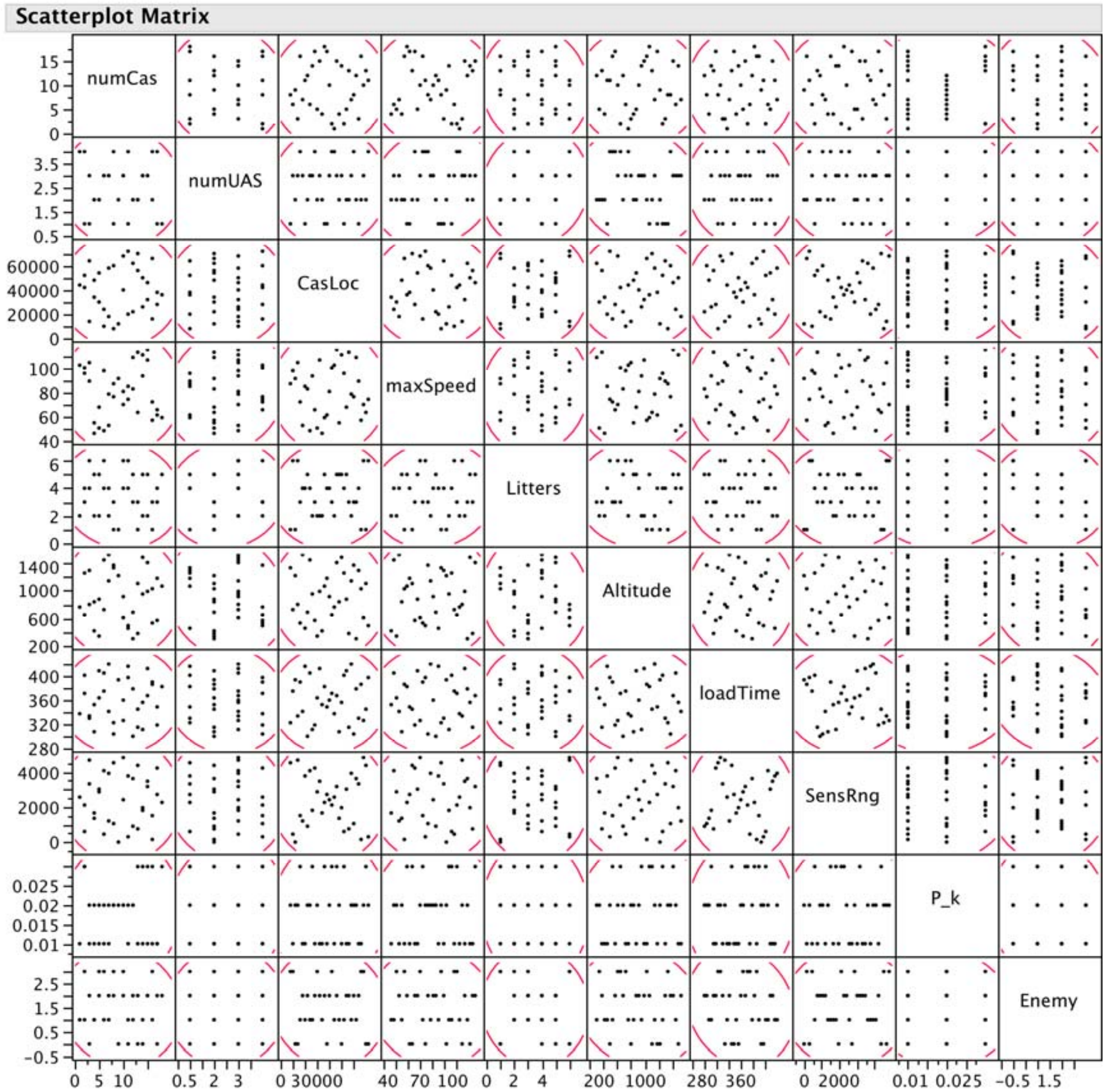

Figure 7. Scatterplot Matrix

The near orthogonal nature of the Latin Hypercubes ensures that the experimental factors are not correlated. Figure 8 shows the negligible correlation between factors.

Correlations

	numCas	numUAS	CasLoc	maxSpeed	Litters	Altitude	loadTime	SensRng	P_k	Enemy
numCas	1.0000	−0.0230	0.0306	−0.0039	−0.0690	0.0038	0.0229	−0.0038	0.0648	−0.0721
numUAS	−0.0230	1.0000	0.0193	0.1352	0.0834	−0.1159	−0.0644	−0.0580	0.0847	0.0075
CasLoc	0.0306	0.0193	1.0000	−0.0000	0.0449	−0.0201	0.0100	0.0000	0.0294	−0.0515
maxSpeed	−0.0039	0.1352	−0.0000	1.0000	0.0817	−0.0000	−0.0074	0.0001	0.0546	−0.0644
Litters	−0.0690	0.0834	0.0449	0.0817	1.0000	−0.0449	−0.0367	−0.0163	−0.0233	−0.0346
Altitude	0.0038	−0.1159	−0.0201	−0.0000	−0.0449	1.0000	0.0100	0.0107	0.0841	−0.1159
loadTime	0.0229	−0.0644	0.0100	−0.0074	−0.0367	0.0100	1.0000	−0.0020	0.0336	−0.1417
SensRng	−0.0038	−0.0580	0.0000	0.0001	−0.0163	0.0107	−0.0020	1.0000	0.0294	0.0129
P_k	0.0648	0.0847	0.0294	0.0546	−0.0233	0.0841	0.0336	0.0294	1.0000	−0.0773
Enemy	−0.0721	0.0075	−0.0515	−0.0644	−0.0346	−0.1159	−0.1417	0.0129	−0.0773	1.0000

Figure 8. Factor Correlation Matrix

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IV. DATA ANALYSIS PROVIDES INSIGHTS

The JTEAM simulation is run on the computer cluster at NPS using the problem definition, scenario, and MOEs explained in previous chapters. The generated output is then processed into a useable format. An exhaustive process of statistical analysis is applied after post-processing to gain insights on unmanned CASEVAC. For this simulated scenario, this analysis is accomplished with JMP 7.0 Statistical Discovery Software and focuses on the research questions outlined in the first chapter:

- What is the probability distribution of mission completion time?
- What are the most influential factors that affect mission completion time?

A. DATA PROCESSING IS THE FIRST STEP IN ANALYSIS

After an experiment is complete, the NPS cluster produces output in comma separated value (CSV) text files. These CSV files contain information that ranges from the design of experiments to MOEs, which include the time of the casualty, the time of the CASEVAC request, and the departure and return times for the UAS. Using JMP, the multiple CSV files are consolidated into one manageable table.

An iterative process is applied to calculate mean completion time. During the JTEAM simulation, each design point is replicated 30 times. A CASEVAC completion time is attached to each replication. The mean of the replications is recorded for each design point.

Successful CASEVAC missions are completed within 60 minutes. The percent complete is calculated by dividing the number of successful CASEVAC drop offs by the total number of CASEVAC requests.

A distribution of the mean completion times is provided in Figure 9. The summary includes the distribution data and 95% confidence intervals. Based on the distribution of Mean Completion Times (MCT), the average CASEVAC mission is completed in 57.64 minutes.

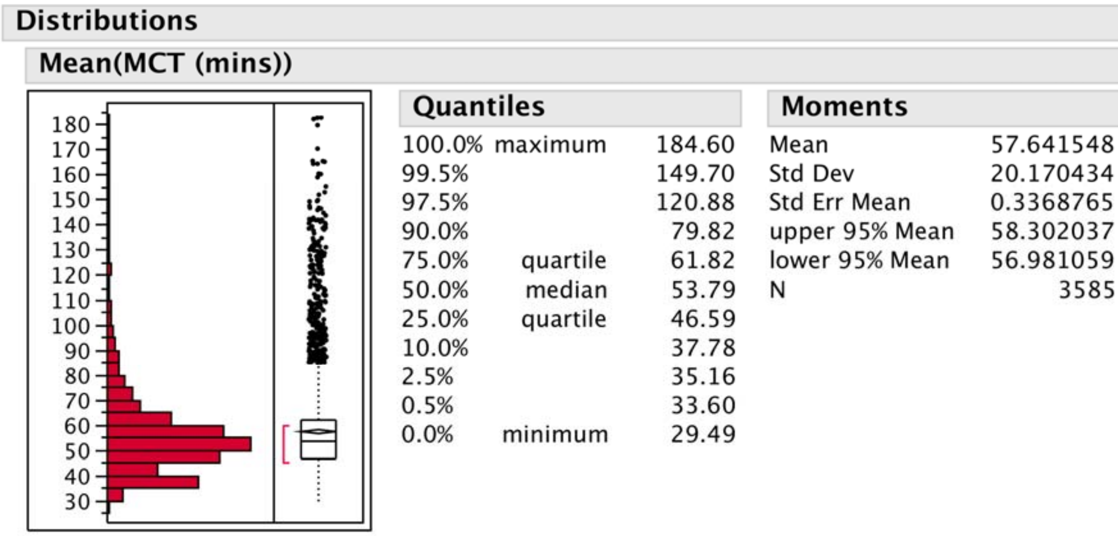


Figure 9. *MCT* Distribution

1. Success Determined

CASEVAC mission success is determined using 3960 simulation runs. Of these runs, 3585 were completed. The remaining 375 runs represent missions that resulted in all UASs being shot down by the enemy threat. Table 2 shows the mean *MCTs*, number of runs within each *MCT* range, and the corresponding completion percentage.

***MCT* (minutes)**	**Number of Runs**	**Percent Complete**
< 60	2554	64.5
< 70	467	11.8
< 80	213	5.38
< 90	114	2.88
< 100	73	1.84
> 100	164	4.14

Table 2. CASEVAC Mission completion percentages

With roughly 9.45% of the simulation runs resulting in UASs being shot down before CASEVACs were completed, this analysis focuses on the remaining 90.55% of runs that are completed to determine keys to success.

B. FACTORS IMPORTANCE DETERMINED

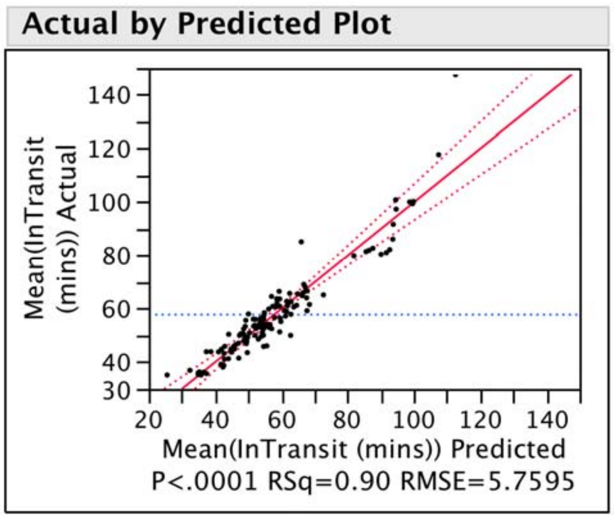
Performance factors are evaluated to determine their effect on mission success. Their influence was determined using regression analysis and partition trees. Regression analysis is a statistical technique used to investigate and determine the relationship between variables. Stepwise regression is used because evaluating all possible regressions can be burdensome computationally and to prevent over fitting.

1. Stepwise Regression Evaluates a Subset of the Model

Stepwise regression evaluates a subset of the model by adding and deleting regressors one at a time. This procedure requires two cutoff values that measure significance. The first value is referred to as F-in and the second F-out. The first regressor is chosen by evaluating significance. The regressor with largest F statistic value is considered for the stepwise regression model only if its F statistic exceeds the F-in. As another regressor is added, the previously selected regressors are reevaluated. This reevaluation determines if the relative value added has been affected by the most recent addition. Previously added regressor's are removed if their partial F statistic value is less than F-out (Montgomery, Peck, & Vinning, 2006).

The stepwise regression model evaluates main effects and two-way interactions of the 10 key factors on MCT overall excursions. A 0.1 level of significance is used (F-in and F-out are set at 0.1) to develop this model. The results identified four influential main effects and four two-way interactions. The significant main effects are: Casualty Location, Maximum Speed, Number of UASs, and Number of Casualties. The significant two-way interactions are: Number of UASs and Enemy Category, Maximum Speed and Casualty Location, Load Time and Altitude, and Number of UASs and Number of Casualties.

The model achieved an R-Squared of 0.90, which means 90% of the variability of the mean mission completion time is explained by the most influential factors. Figure 10 shows the regression model. The actual versus predicted plot indicates how closely the model explains mean completion time. This plot is determined by comparing the observations to the diagonal line. The dashed blue line indicates the overall mean completion time.



Summary of Fit

RSquare	0.900773
RSquare Adj	0.887942
Root Mean Square Error	5.759465
Mean of Response	57.8476
Observations (or Sum Wgts)	132

Figure 10. Actual by Predicted *MCT* and Summary of Fit

The low p-value for the F statistic in the Analysis of Variance table, as seen in Figure 11, indicates the high significance of the model.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	34930.659	2328.71	70.2023
Error	116	3847.887	33.17	**Prob > F**
C. Total	131	38778.546		<.0001*

Figure 11. Analysis of Variance Table shows Significance

The relative influence of each factor is determined by t-Ratio. The higher the absolute value of the ratio indicates more relative influence on the MOE. Figure 12 lists the factors in order of significance (t-Ratio). As shown, the t-Ratio for Casualty Location (CasLoc) is 23.26. This is the highest of any factor, which means that CasLoc is the most significant factor in the determination of MCT. This value is also positively correlated, which means when CasLoc is increased, the MCT increases as well. Maximum Speed (maxSpeed) is the next most significant factor with a t-Ratio of –11.42 and is negatively correlated. As maxSpeed increases, MCT decreases.

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
casLoc	0.000609	2.619e-5	23.26	<.0001*
maxSpeed	-0.277927	0.024327	-11.42	<.0001*
numUAS	-5.125142	0.513297	-9.98	<.0001*
numCas	0.8916811	0.100333	8.89	<.0001*
(numUAS-2.51515)*EnemyCat[0]	-6.389492	0.878413	-7.27	<.0001*
(maxSpeed-81.0006)*(casLoc-40225)	-9.73e-6	1.608e-6	-6.05	<.0001*
(loadTime-120)*(UAS_altitude-914.4)	-0.000193	4.353e-5	-4.43	<.0001*
(numUAS-2.51515)*(numCas-9.51515)	-0.342031	0.115376	-2.96	0.0037*
loadTime	0.0348087	0.014082	2.47	0.0149*
EnemyCat[0]	1.9806982	0.868272	2.28	0.0244*
(numUAS-2.51515)*EnemyCat[1]	1.3528096	0.878413	1.54	0.1263
(numUAS-2.51515)*EnemyCat[2]	1.3382497	0.878413	1.52	0.1304
EnemyCat[2]	0.7379464	0.868272	0.85	0.3971
UAS_altitude	-0.000686	0.001391	-0.49	0.6227
EnemyCat[1]	-0.127928	0.868272	-0.15	0.8831

Figure 12. Sorted Parameter Estimates. The t Ratio column shows the relative influence on the *MCT*

2. Partition Trees Show Relative Importance

Partition trees recursively split data according to a relationship between the *X* (factor) and *Y* (response) values. It finds a set of groupings of X values that best predict a Y value. The partition tree does this by exhaustively searching all possible groupings. Splits of the data are done recursively, forming a tree of decision rules until the desired fit is reached. A partition tree created on data from 3960 JTEAM runs on all the factors for the mean *MCT* MOE is shown in Figure 13. The partition tree achieves an R-squared of 0.81.

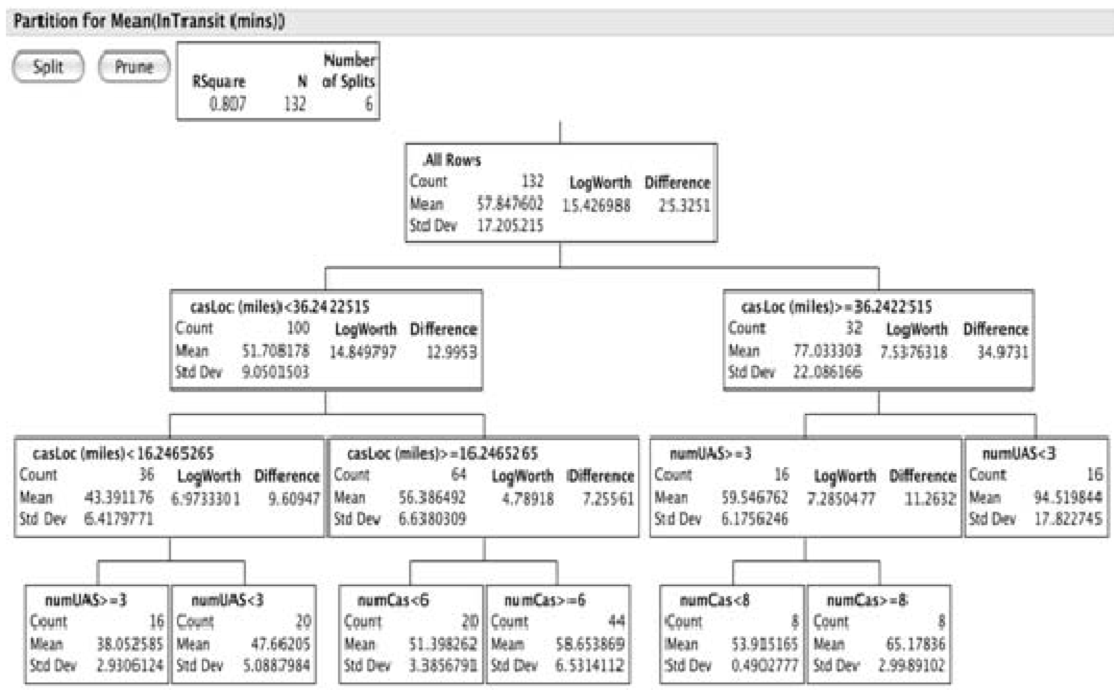


Figure 13. Partition Tree split on data for Mean *MCT*

The first split is on *CasLoc*, which was also the most influential factor identified by the regression analysis. The partition tree shows the split at a distance of 36.2 miles from the FOB. Casualties that occur inside of 36.2 miles are delivered to surgical care, on average, 26 minutes sooner than those that occur at distances greater than 36.2 miles.

The second split is also on *CasLoc*. When casualties occur less than 16.2 miles away from the FOB, the mean *MCT* is slightly over 43 minutes. However, when casualties are over 16.2 miles away from the FOB but less than 36.2 miles, the mean *MCT* increases to over 56 minutes.

The last four splits alternate on the number of UASs (*numUAS*) and the number of casualties (*numCas*). The best mean *MCTs* are achieved when the casualty location is less than 16.2 miles from the FOB and there are at least three UASs.

C. CONTROLLABLE FACTORS ARE EVALUATED

The results of the linear regression and partition tree analysis outlined factors that have significant influence on mission completion time. Casualty location is the most influential factor, but is uncontrollable; as is the number of casualties. The most significant controllable factors are maximum airspeed and the number of UASs. The number of litters is also important to determine the configuration of each UAS. A detailed analysis is conducted to determine the effects of these factors on MCT and mission success.

1. Maximum Speed Plays Important Role

The airspeed of the UAS is the most significant controllable factor. Although a regression cannot be fit to the interaction of *MCT* and *maxSpeed*, Figure 14 shows there is a general trend: *MCT* decreases when speed increases.

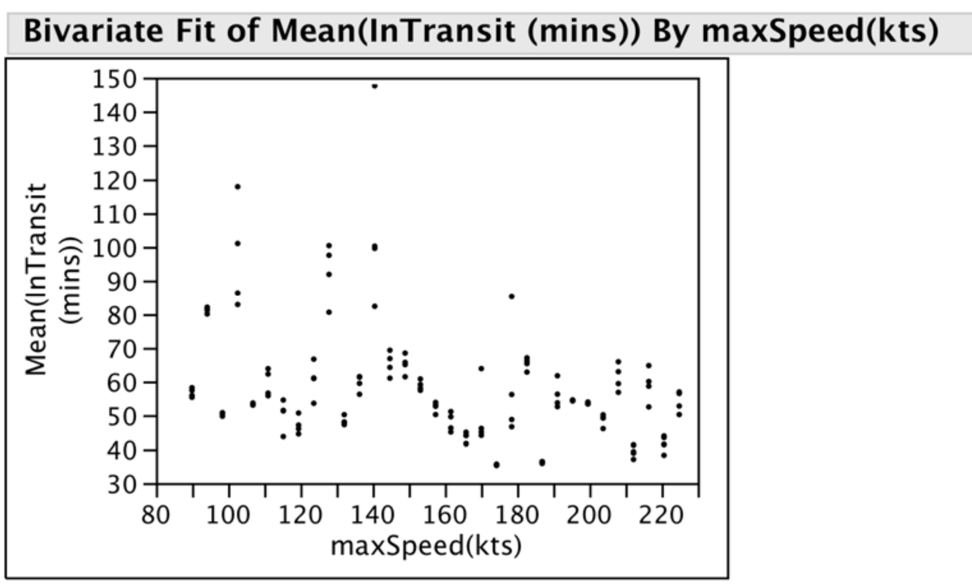


Figure 14. *MCT* versus Airspeed

There is a trend when *maxSpeed* is plotted against *MCT*. Figure 15 shows this interaction.

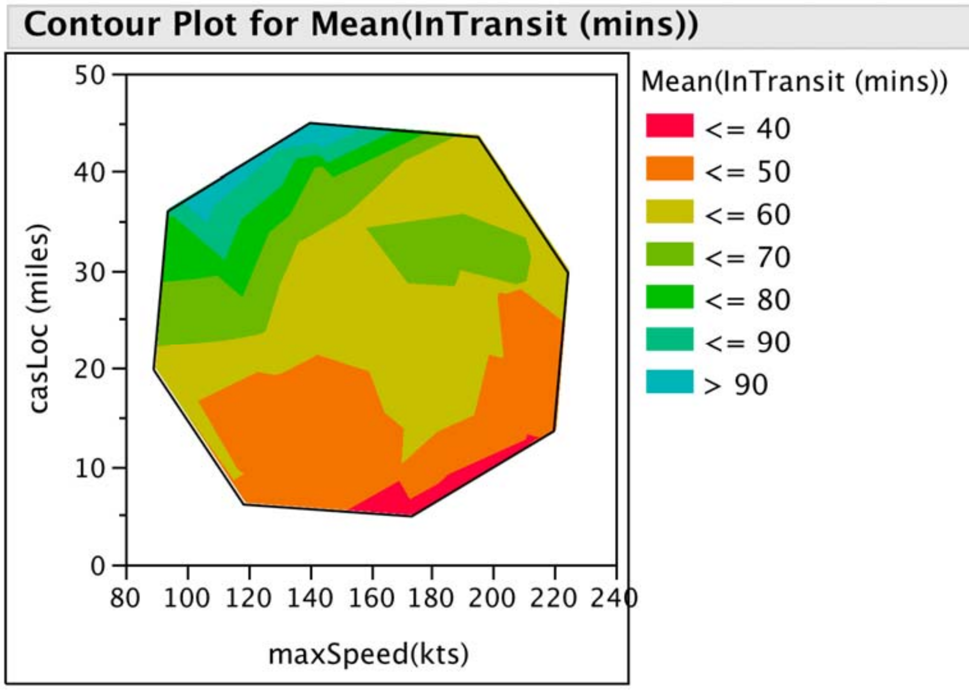


Figure 15. Contour Plot of *CasLoc* versus *maxSpeed*

In the contour plot, the MCTs in red, orange, and yellow are acceptable. As depicted, there is a trend with required airspeed and distance from surgical care. A group of replications, indicated by a green region within the yellow, do not follow this trend. Simulation runs characterized by 14 casualties cause this anomaly. The large number of casualties causes the longer MCT, not the distance from surgical care.

The nature of these plots is that a large amount of the variability in the prediction formula is due to the experimental design. Although the model generally predicts the simulation output well, there is a lot of volatility in a two-way slice of the data due to the way parameters are varied in the NOLH. For example, maxSpeed was varied simultaneously with other factors in an exploratory fashion, so not all possible combinations are observed. It is possible that a sudden upturn in the MOE is due to another parameter that was varied simultaneously.

2. The Number of UASs Examined

This analysis compares the performance of the number of UASs across the range of simulation runs. The *MCT* for each is shown in Figure 16.

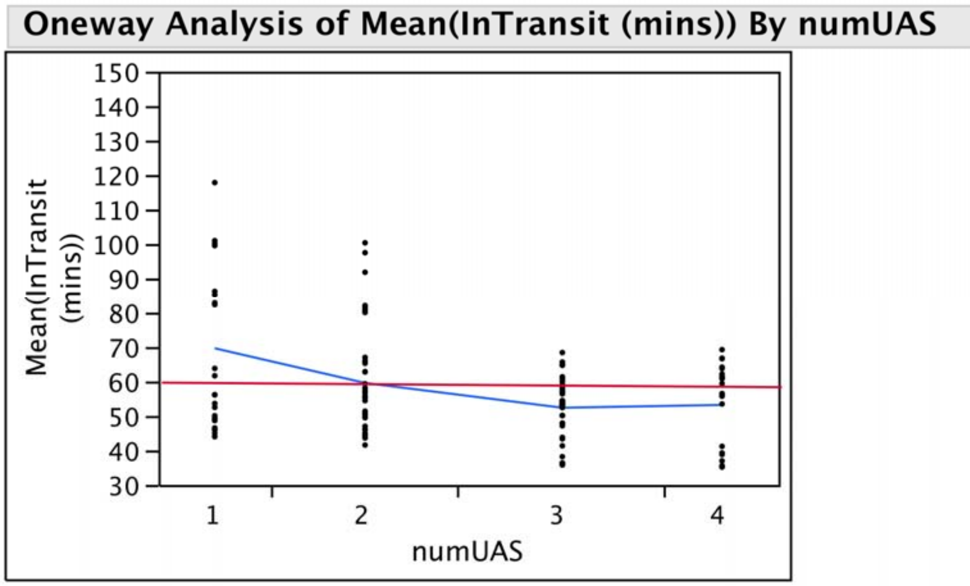


Figure 16. *MCT* versus the Number of UASs

The plot shows the *MCT*s of the simulation runs with the different number of UASs. The blue line connects the means of the different factor levels. The red line depicts the golden hour. CASEVACs must be completed within this time to be classified successful. The *MCT* decreases as the number of UASs is increased. *MCT* decreases noticeably when the number of UASs is increased from one to two. Another significant decrease in *MCT* is observed when the number of UASs is increased to three. No significant difference in *MCT* is noted when UASs are increased to four. Figure 17 shows the comparison of the different means.

Comparisons for each pair using Student's t

t	Alpha
1.97867	0.05

Level		Mean
1	A	69.627475
2	B	59.575462
4	B C	53.206731
3	C	52.382821

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value
1	3	17.24465	9.12197	25.36734	<.0001*
1	4	16.42074	7.18044	25.66105	0.0006*
1	2	10.05201	1.78723	18.31679	0.0175*
2	3	7.19264	0.19969	14.18559	0.0439*
2	4	6.36873	-1.89605	14.63351	0.1298
4	3	0.82391	-7.29877	8.94659	0.8412

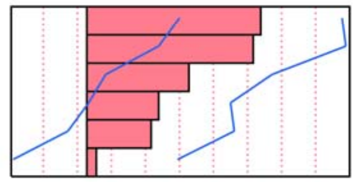


Figure 17. Mean Comparisons for *numUAS*

This comparison shows that there is a significant difference between the mean times for one, two, and three UASs. The high p-value indicates no significant difference between the mean times of three and four UASs.

3. The Number of Litters Analyzed

Although the number of rescue litters is not significant in the determination of *MCT*, the analysis of the combined effect of the number of litters and the number of UASs is the necessary first step to determine allocation and configuration requirements. Figure 18 shows the interaction of the number of litters and number of UASs and their effect on *MCT*. As the number of litters is increased, the *MCT* decreases.

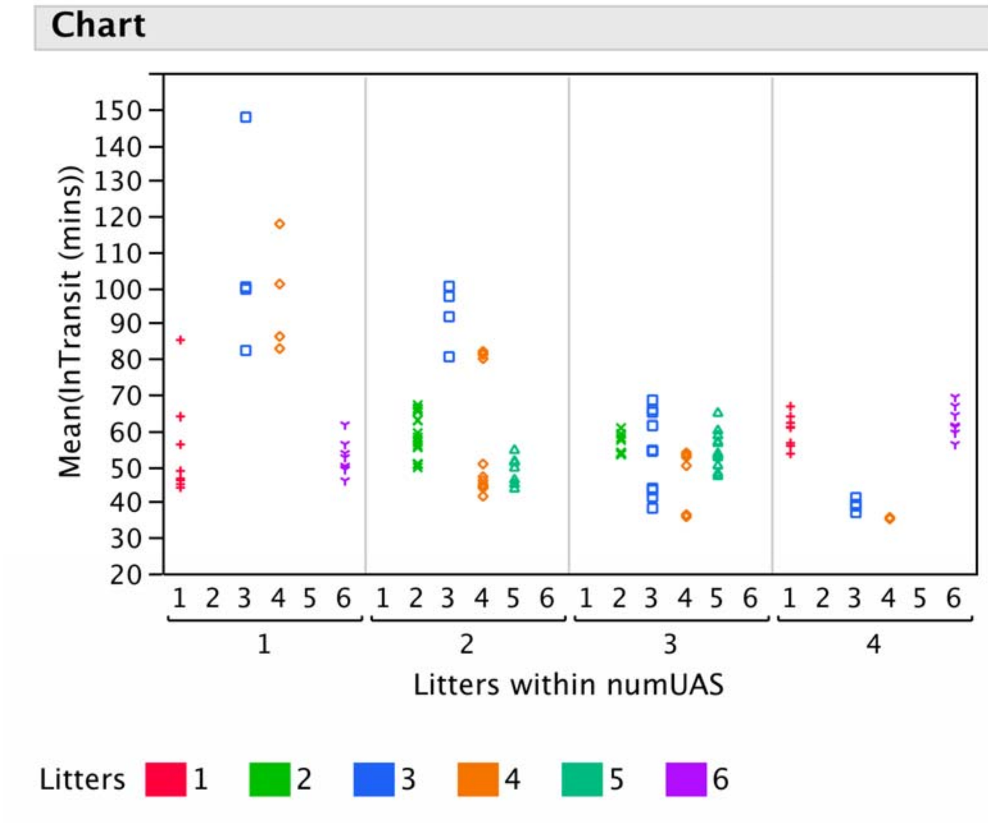


Figure 18. *MCT* versus Number of Litters within Number of UASs

This interaction is also depicted in the contour plot in Figure 19.

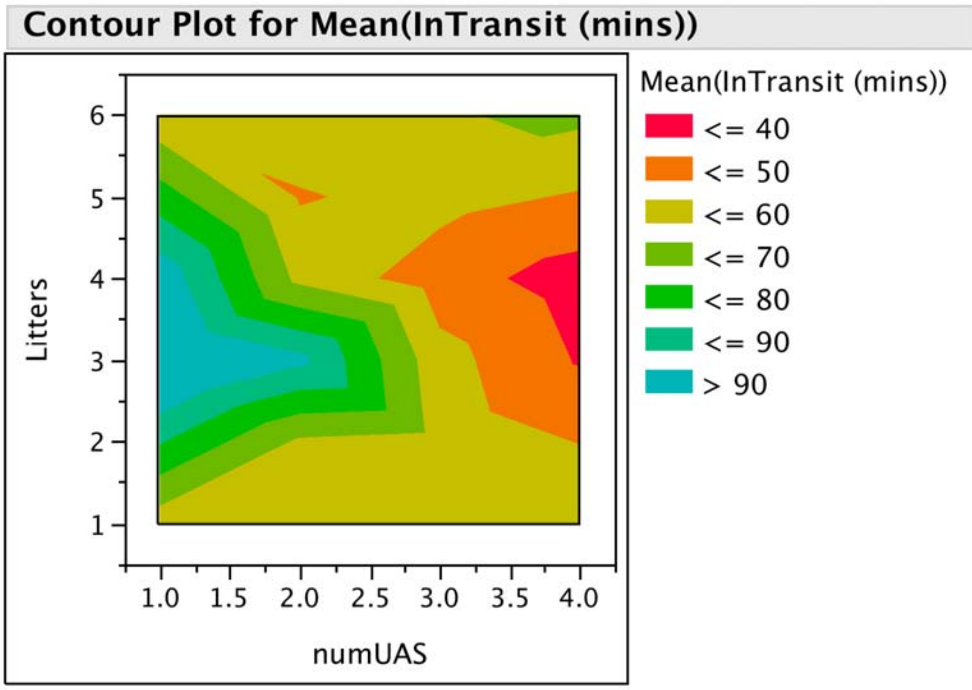


Figure 19. *numUAS* versus Litters

In the contour plot, red, orange, and yellow depict acceptable *MCTs*. Large distances (greater than 40 miles) between casualties and care locations cause the blue and green areas. In order to achieve a 60-minute or less *MCT*, at least three UASs must be available.

4. Altitude Plays a Role in Mission Success

The last aircraft characteristic is altitude. As seen in Figure 20, when *UAS altitude* is plotted against *MCT* no trend is noticed.

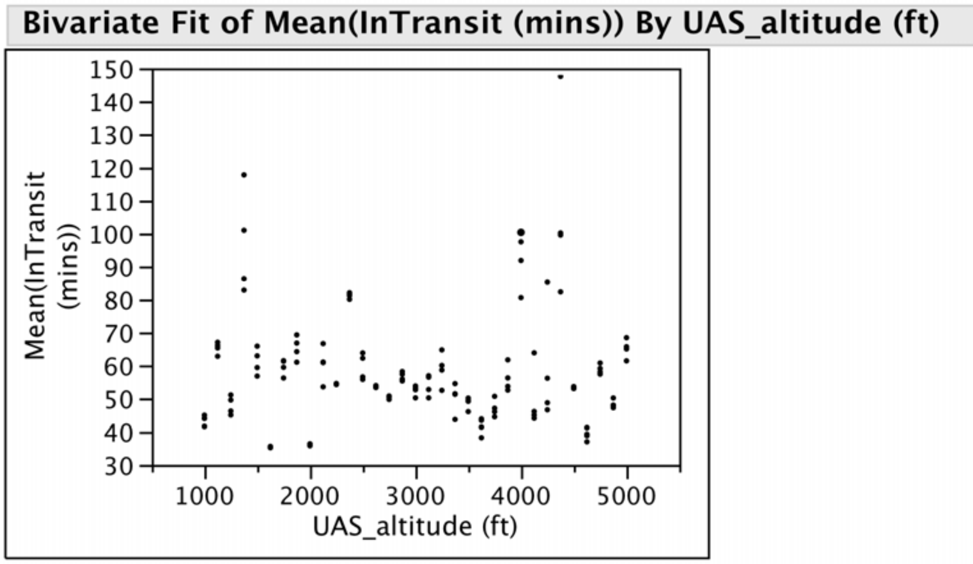


Figure 20. MCT versus UAS altitude

Because acceptable MCTs are achieved across the range of altitudes, no altitude is more efficient. This is also the case with the interaction of *UAS altitude* and *maxSpeed.* Figure 21 shows how this interaction improves the survivability of the UAS.

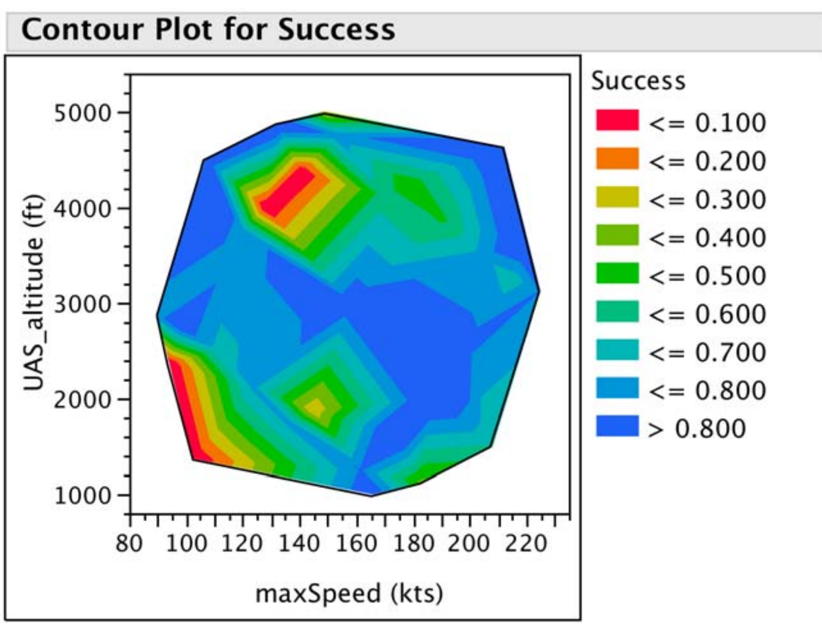


Figure 21. Contour Plot of *UAS altitude* versus *maxSpeed* and their relationship to Survivability

Over 80%, shown in blue, of the completed flights survive throughout the range of altitudes, regardless of airspeed. The low percentages of success, depicted by red and orange. These percentages are caused by simulation runs with high numbers of casualties and low numbers of UASs.

V. UAS CASEVAC WITHIN THE GOLDEN HOUR IS FEASIBLE

The purpose of this thesis is to determine the probability distribution of mission completion times and to identify the most influential factors on mission success, for this scenario. The modeled scenario is derived from a planned MCWL experiment and the analysis provides insights into the development of future TTPs for unmanned CASEVAC in the distributed environment. In addition, this simulation serves as the foundation for future unmanned CASEVAC research.

A. UAS REQUIREMENTS DETERMINED

Regression analysis and partition trees are used to determine the most influential factors that affect CASEVAC *MCT*. The most significant factor that affects *MCT* is the casualty location. Unfortunately, this factor is uncontrollable. The most influential controllable factors are the maximum speed of the UAS and the number of UASs available. The configuration of each UAS was also determined by analyzing the number of litters on board. Although the flight altitude of the UAS is controllable, no significant decrease in *MCT* is achieved by varying this factor.

1. Number of UASs

In the simulation, the number of UASs is varied between one and four. *MCT* was used to determine the number of UASs necessary for mission success. When one UAS is used, the *MCT* is 69. 6 minutes. *MCT* decreases to 59.6 minutes when an additional UAS is added. When three UASs are available, the *MCT* drops to 53.2 minutes. There is no significant difference between the *MCT* of three and four UASs (differs by less than 1 minute). Although the *MCT* achieved by two UASs satisfies the golden hour requirement, three UASs provide a significant decrease in *MCT*. This decrease could be linked to the number of platoons that experience casualties; however, this thesis does not consider force composition.

2. Number of Litters per UAS

The number of litters that each UAS carried varied between one and six. As with the number of UASs, *MCT* is used to determine which provides the fastest recovery time. The number of litters necessary to achieve the golden hour requirement varies as the number of UASs is changed. When one UAS is available, six litters are needed. As the number of UASs is increased to two, the required number of litters goes down to four. When three UASs are available, *MCTs* within the golden hour are observed for across the range of all possible numbers of litters.

3. Airspeed Required is Based on the Number of UASs

UAS airspeed was varied from 90-225 kts. *MCT* is used to determine effectiveness. The airspeed required to achieve an acceptable *MCT* varies with the number of UASs and the number and location of casualties. As the number of UASs are increased, the necessary airspeed decreases.

a. One *UAS*

An airspeed of 150 kts is required when casualties are 15 miles away from care and 185 kts when 30 miles away. No cases are observed with one UAS achieving the *MCT* requirement when casualties are farther than 30 miles from surgical care.

With up to seven casualties, 160 kts is required to achieve an acceptable *MCT*. If there are eight casualties, the UAS must fly at 185 kts. In no case does one UAS retrieve more than eight casualties within the golden hour requirement.

b. Two *UASs*

Flying at 90 kts enables two UASs to respond to casualties that are 20 miles away. Increasing the airspeed to 190 kts extends the range to 27 miles. Two UASs are inadequate for casualties greater than 30 miles away.

To respond to 12 casualties, these UAS must fly at 115 kts. If the number of casualties grows to 18, then the UASs must be able to fly at 125 kts.

c. Three *UASs*

Most of the observed *MCT*s across the range of airspeeds meet the golden hour requirement. The exception occurs when the distance to casualties is 40 miles. At this distance, UAS airspeed must be greater than 160 kts.

The observed *MCTs* for the number of casualties meet the golden hour requirement as well. The modeled design points show success while responding to 5 casualties at 105 kts and 15 casualties at 215 kts.

d. Four *UASs*

No significant difference between three and four UASs was observed.

4. UAS Recommendations

The detailed quantitative analysis of the simulation results reveals requirements for the number of UASs, the number of litters, and the airspeed required to respond to the simulated number and location of casualties within the golden hour. Based on initial results, three UASs with two litters per UAS are recommended. With this allocation of assets, the capabilities of the current concept demonstrator, Boeing's ULB, appear sufficient to achieve an acceptable *MCT*.

B. FOLLOW-ON RESEARCH

The insights from this thesis are based on the modeled scenario. The analysis focuses on successful CASEVAC missions. Future analysis should incorporate the affect of enemy category on the total number of casualties that are delivered to surgical care. Further analysis should also include the findings of ECO LOE 3.3 and in corporate an updated scenario.

This scenario should include more detail surrounding UAS flight operations. The maintenance cycle, usage rates, and ability to be re-tasked from logistic missions to CASEVACs are of interest. Opportunism, allowing the UAS to retrieve more casualties than were requested, should be modeled (casualties occurred while the UAS was en route that were not included in the request).

The following are possible follow-on research stemming from this thesis:

- Model unmanned aerial CASEVAC in conjunction with ground evacuation.
- Compare the performance of UAS CASEVAC with that of the MV–22 Osprey, based on mission performance, maintenance cycle, and logistic requirements.

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